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LATITUDE AND LONGITUDE

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# LATITUDE AND LONGITUDE:

*HOW TO FIND THEM.*

W. J. MILLAR, C.E.

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# LATITUDE

AND

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## *HOW TO FIND THEM.*

BY

W. J. MILLAR, C.E.,

MEMBER OF THE EDINBURGH MATHEMATICAL SOCIETY; LATE SECRETARY, INSTITUTION OF ENGINEERS AND SHIPBUILDERS IN SCOTLAND; AUTHOR OF "AN INTRODUCTION TO THE DIFFERENTIAL AND INTEGRAL CALCULUS," ETC.

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# EDITOR'S PREFATORY NOTE.

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THIS SERIES has been designed to meet the growing desire on the part of Officers in the Mercantile Marine for a MORE SCIENTIFIC INSIGHT into the principles of their profession, and the sciences upon which the Art of Navigation is founded. The treatises are, for the most part, WRITTEN BY SAILORS FOR SAILORS; and, where this is not the case, by authors who have special knowledge of the subjects dealt with and their application to the Sailor's life. The treatment will be thoroughly scientific, yet as free as possible from abstruse technicalities, and the style such as will render it easy for the young sailor to gain a knowledge of the elements of his profession by private reading and without difficulty.

E. B.

LONDON, *April, 1896.*

# AUTHOR'S PREFACE.

THE object of the Author in the present work is to present to the reader, in a simple manner, some of those problems that relate to the finding of position at Sea, by means of Altitudes of the Sun or Stars. No attempt is made to go beyond this, as the Student of Navigation must refer to more complete treatises for a mastery of the subject. It is hoped, however, that the diagrams and examples may assist in conveying to the reader a definite conception of the principles underlying the well-known methods adopted for determining Latitude and Longitude at Sea.

GLASGOW, *April*, 1896.

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## LATITUDE AND LONGITUDE.

# LATITUDE AND LONGITUDE:

## *HOW TO FIND THEM.*

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### INTRODUCTORY.

#### MATHEMATICAL EXPRESSIONS.

To those who have not much acquaintance with mathematical expressions, the following notes may be of service before proceeding to the subject proper of the book itself:—

**Proportions.**—*Proportions* or *ratios* are expressed as follows:—

$$(1)\ 2 : 4 :: 8 : 16, \text{ or } (2)\ \frac{2}{4} = \frac{8}{16}$$

In (1) we have a proportion stated in the form of 2 *is to* 4 *as* 8 *is to* 16.

In (2) we have 2 *divided* by 4 *equal* to 8 *divided* by 16, and this also forms an *equation*—that is to say, the one side of the statement is equal to the other.

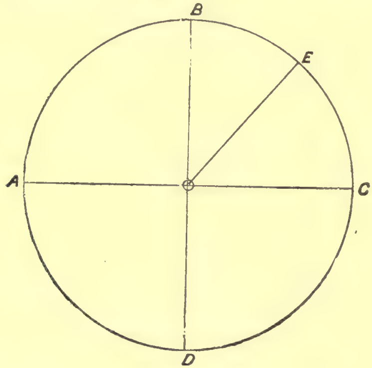
The form in which the first of these expressions (1) is stated is commonly used in *simple proportion*, or the Rule of Three, where we have the question appearing in such a form as $2 : 4 :: 8 : x$, $x$ being an unknown quantity, and one which we wish to know. To find $x$, we *multiply* the 4 by the 8, and *divide* by the 2. The result or *quotient* is equal to $x$. Thus $\frac{4 \times 8}{2} = 16$.

In the fractional form shown by (2) we have $\frac{2}{4} = \frac{8}{x}$, and to find the value of $x$ we may proceed as follows:—Multiply *both* sides of this equation by 4, and we have $2 = \frac{32}{x}$; multiply both sides by $x$, and we have $2x = 32$. Divide both sides by 2, and we have $x = 16$.

It will be noticed here that whatever we do on one side of the equation we must do the same on the other, as otherwise the two sides would not continue equal during the working out of the unknown part of the equation.

**Angles.**—Angles are measured in certain equal parts called *degrees.*

Thus the whole circle is supposed to be divided into 360 equal parts or degrees; if we take four equal large divisions




or *quadrants* of the circle, such as A B, B C, C D, and D A, we have in each of these $\frac{360}{4} = 90$ degrees. That is to say, the *arc* or part of the circle B C is supposed to be divided into 90 equal parts; for the purposes of accurate measurement, each of these parts is supposed to be divided into 60 equal parts called *minutes*, and each of these again into further subdivisions of 60 equal parts called *seconds.*

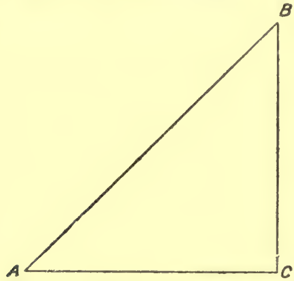
| | | |
|---|---|---|
| Degrees are noted thus, | . . . | 90° |
| Minutes ,, | . . . | 60′ |
| Seconds ,, | . . . | 60″ |

So that an angle or arc measuring, say, 51 degrees, 48 minutes, 35 seconds, would be written thus:—51° 48′ 35″

If the angle E O C be taken away from the angle B O C, we have the angle B O E left; this angle is called the *complement* of E O C. Thus if E O C = 45°, then 90° - 45° = 45°; and if E O C = 30°, then 90° - 30° = 60°; 45° and 60° are, therefore, the complements of 45° and 30°

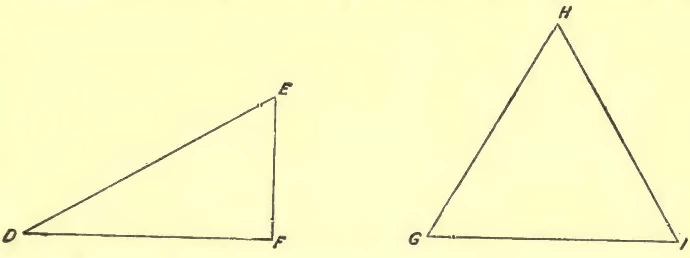
Again, if the angle E O C be taken from the sum of the right angles A O B and B O C, we have the angle A O E left; it is called the *supplement* of E O C. Thus, if E O C be 60°, then 180° - 60° = 120°; and this is the supplement of the angle 60°.

**Triangles.**—Let A B C be a right-angled triangle, and let the sides A C and B C be equal to each other. The




angle A C B is = 90°, and the angle B A C and A B C are each equal to 45°, because the three angles of a triangle are equal to *two right angles*, and the angles at A and B are complementary to each other, as together they make one right angle or 90°.

Again, in the right-angled triangle D E F let the side E F be one-half of D E, then the angles at D and E are respectively




equal to 30° and 60°; also in the equilateral (equal sided) triangle G H I, the three sides being equal, the three angles at G, H, and I are also equal, and they each measure 60°, because 60° + 60° + 60° = 180°.

Now, if the sides of triangles varied in length in the same proportion as the angles, it would be very easy to measure the various parts. Thus, in the triangle D E F, if the side D E be made equal to 10, the side E F will be equal to 5, and side D F to 8·7 nearly. The sides have, therefore, the following values, 10, 5, and 8·7, and the angles opposite the sides, 90°, 30°, and 60°. Here it will be seen that although the side E F is one-half of the side D E, yet the angle at D (*opposite* to the side E F) being 30°, is only *one-third* of the angle at F (*opposite* the side D E), which is 90°; hence the sides do not vary as the angles opposite them.

In the above example we have taken the value of the sides of the triangle D E F as 10, 5, and 8·7; the relations of the sides and angles would be just the same supposing we take any other values in the same proportions. Thus, let the above values be all divided by 10, then we have 1, ·5, and ·866 as the values of the sides.

In this case the *hypothenuse* (or side opposite the right angle) is equal to 1 (or unity), and the other sides to decimal parts of 1.

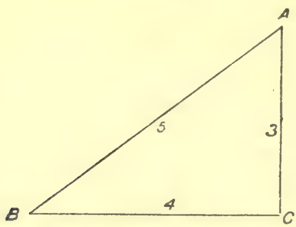
It is the province of trigonometry to discuss these questions, and from it we find that the sides of triangles vary as the *sines* of the angles opposite them.

As it is important that this should be thoroughly understood, a short reference to what are termed the *trigonometrical ratios* will now be made.

**Trigonometrical Ratios.**—These trigonometrical ratios enable us to utilise triangles for the purpose of measurement; they are known as *sines*, *cosines*, *tangents*, *cotangents*, *secants*, and *cosecants*, and their numerical values have been tabulated for reference in books of tables (see the volume on *Algebra and Trigonometry* in Griffin's *Nautical Series*).

The trigonometrical ratios are simply the relative values of the sides of a right-angled triangle. Thus, in the triangle A B C, in which the angle A C B is a right angle,

$$\frac{AC}{AB} = \text{sine B and } \frac{BC}{AB} = \text{cosine B.}$$




Let the sides of the triangle have the following values:—
AB = 5, AC = 3, and BC = 4; then sine B $= \frac{3}{5} =$ ·6 and

cosine B $= \frac{4}{5} = \cdot 8$. On reference to a table of natural sines and cosines, we find that ·6 is the sine of an angle of 36° 52′ 11″, and ·8 is the cosine of the same angle.

Again, if we divide AC by BC, we have $\frac{AC}{BC} = \frac{3}{4} = \cdot 75$; this is known as the *tangent* of the angle B; and $\frac{BC}{AC} = \frac{4}{3} = 1 \cdot 333$ is the *cotangent* of the same angle.

Also, $\frac{AB}{BC} = \frac{5}{4} = 1 \cdot 25$ is the *secant* of angle B;

and $\frac{AB}{AC} = \frac{5}{3} = 1 \cdot 666$ is the *cosecant* of the same angle.

We have also the following when the relative values of the sides are those of triangle D E F, p. 3:—

$\frac{EF}{DE} = \frac{\cdot 5}{1} = \cdot 5$, which is the sine of angle D,

and $\frac{DF}{DE} = \frac{\cdot 866}{1} = \cdot 866$, which is the cosine of the same angle.

Also, $\frac{EF}{DF} = \frac{\cdot 500}{\cdot 866} = \cdot 577$, which is the tangent of angle D.

and $\frac{DF}{EF} = \frac{\cdot 866}{\cdot 500} = 1 \cdot 732$, which is the cotangent of the same angle.

$\frac{\text{Sine}}{\text{Cosine}}$ = tangent, or in figures $\frac{\cdot 5}{\cdot 866} = \cdot 577$.

$\frac{\text{Cosine}}{\text{Sine}}$ = cotangent, ,, $\frac{\cdot 866}{\cdot 5} = 1 \cdot 732$.

$\frac{1}{\text{Cosine}}$ = secant, ,, $\frac{1}{\cdot 866} = 1 \cdot 154$.

$\frac{1}{\text{Sine}}$ = cosecant, ,, $\frac{1}{\cdot 5} = 2 \cdot 000$.

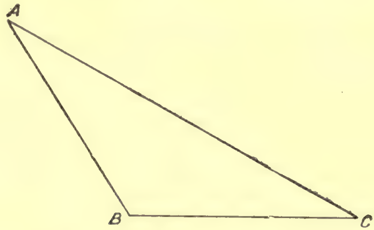
Again, by *Euclid*, I. 47, we have the

$$\text{Sine} = \sqrt{(1 - \cos^2)} = (1 - \cos^2)^{\frac{1}{2}}.$$

and the

$$\text{Cosine} = \sqrt{(1 - \sin^2)} = (1 - \sin^2)^{\frac{1}{2}}.$$

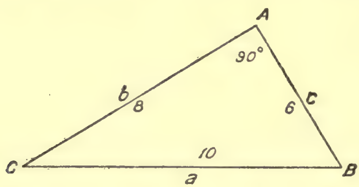
When one of the angles of a triangle, such as B, is greater than 90°, the rule of the sides being proportional to the sines of the angles opposite these angles still holds good. Thus, let the angle B = 120°, we deduct this from 180°, and the difference, 60°, is the angle whose sine we look for in the tables.




Should we require for any purposes of calculation the cosine of B, we find the angle of 60° as before, and turn up the value of the corresponding cosine; but, in this case, we must use a *negative* sign before the value found.

Thus, it will be found that the sine of 60° is equal to ·866, and that the cosine of 60° is ·5. When figures are noted in this way it is always understood that they are *plus* quantities, or have a plus sign (written thus : + ) before them. Negative quantities, on the other hand, must always be indicated by a *minus* sign (written thus : − ), hence, in the case of this obtuse angled triangle, the cosine of the angle B must be considered a negative quantity, and written thus : − ·5.

This is a case of the use of the supplement of the angle whose value we are dealing with. (See also Article 28.)




If in any plane triangle, as C A B, we know the values of the sides $a$, $b$, and $c$, then we can determine the values of the angles A, C, B. The rule for working this out belongs to Plane Trigonometry; but as it is of importance in finding the corresponding rule in Spherical Trigonometry, it may be generally stated here as

$$\cos A = \frac{b^2 + c^2 - a^2}{2\,b\,c}.$$

and

$$a^2 = b^2 + c^2 - 2\,b\,c \cos A.$$

Let the above triangle have the angle A a right angle, and, further, let the sides $a$, $b$, and $c$ be equal to 10, 8, and 6 respectively; then

$$\cos A = \frac{8^2 + 6^2 - 10^2}{2 \times 8 \times 6},$$

or,
$$\cos A = \frac{64 + 36 - 100}{96} = \frac{0}{96} = 0.$$

And on reference to a table of natural cosines, we shall find that ·0 represents an angle of 90°, which is the value of the right angle at A.

To find angle B we have

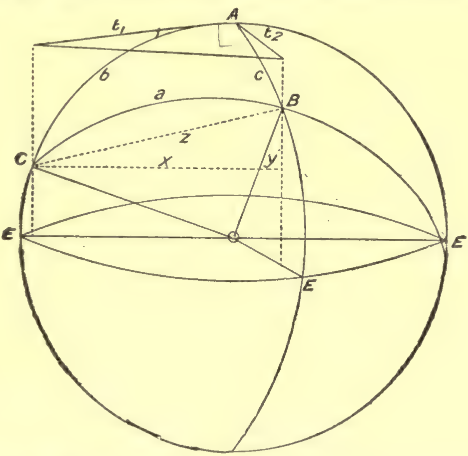
$$\cos B = \frac{a^2 + c^2 - b^2}{2 \times a \times c},$$

or,
$$\cos B = \frac{100 + 36 - 64}{2 \times 10 \times 6} = \frac{72}{120} = \cdot 6,$$

and this we find to be the cosine of an angle of 53° 7′ 49″.

The following diagram and demonstration will show how the corresponding angles are found in spherical trigonometry :—

In this Fig., let O be the centre of a sphere, E O E a diameter,




E E E a great circle, and C B, A C, and A B, or $a$, $b$, and $c$ arcs of great circles ; then A C B is a spherical triangle.

O C, O B, and O E are all radii of the sphere.

The rule for finding angle A is $\cos A = \dfrac{\cos a - \cos b \cos c}{\sin b \sin c}$.

To show how this rule is obtained, we have to consider how we can form a *plane* triangle, and use the rule for such triangles as already given (p. 6).

Let A B E cut E E E at right angles, and let A B E be a quarter of a great circle like A E, then, if the great circle E E E lies in a horizontal plane, the point A will be vertically above O, the centre of the sphere.

If we consider the relation of the parts in the above Fig., we will see that the lines $t_1$ and $t_2$, which are tangents to the arcs $b$ and $c$ (and drawn from the point of intersection at A), are equal to the sines of the arcs $b$ and $c$. We have thus two known sides of a plane triangle. The third side will be equal to the dotted line $x$, and to find $x$ we have to consider the right-angled triangle $x\,y\,z$; $z$ is the chord of the arc C B. In this triangle $z^2 = x^2 + y^2$ (*Euclid*, I. 47); hence $x^2 = z^2 - y^2$. Now, since O C and O B are radii of the sphere, they are equal to each other; let their value be represented by 1; then we have, by rule just given for plane triangles (see p. 6)—

$$z^2 = 1^2 + 1^2 - 2 \times 1 \times 1 \cos a.$$

Again, $y$ will be equal to the difference of the cosines of $b$ and $c$; hence

$$y^2 = (\cos c - \cos b)^2.$$

Then

$$x^2 = 2 - 2 \cos a - (\cos c - \cos b)^2.$$

Therefore,

$$\cos A = \frac{\sin^2 b + \sin^2 c - (2 - 2 \cos a - (\cos c - \cos b)^2)}{2 \sin b \, \sin c},$$

or,

$$\cos A = \sin^2 b + \sin^2 c - 2 + 2 \cos a + \cos^2 c - 2 \cos c \cos b + \cos^2 b;$$

but

$$\sin^2 b = 1 - \cos^2 b, \text{ and } \sin^2 c = 1 - \cos^2 c.$$

Therefore, by substitution we have—

$$\cos A = \frac{1 - \cos^2 b + 1 - \cos^2 c - 2 + 2 \cos a + \cos^2 c - 2 \cos c \cos b + \cos^2 b}{2 \sin b \sin c};$$

and, grouping and cancelling, we have finally—

$$\cos A = \frac{\cos a - \cos b \cos c}{\sin b \sin c}.$$

**Logarithms.**—Logarithms are a series of numbers, by means of which calculations involving the use of large groups of figures are much facilitated.

Thus, if we wish to multiply any two numbers together, we take the logarithms of the numbers and *add* them together; the result, or sum, is the logarithm of the product of the two numbers.

Logarithms may be said to be numbers in *arithmetical progression*, whilst the numbers they represent are in *geometrical progression.*

| | | |
|---|---|---|
| Thus the logarithm of | 10 is 1, | |
| „ „ | 100 is 2, | |
| „ „ | 1,000 is 3, | |
| „ „ | 10,000 is 4, | |
| „ „ | 100,000 is 5, | and so on. |

Here, 1, 2, 3, 4, and 5 are the logarithms, and 10, 100, 1,000, 10,000, and 100,000 are the corresponding numbers.

It will be seen from this that these logarithms are simply the powers to which the number 10 is raised—

$$10^1, \quad 10^2, \quad 10^3, \quad 10^4, \quad \text{and} \quad 10^5,$$

being the same thing as—

10, 100, 1,000, 10,000, and 100,000.

Now, if we *multiply* two numbers, such as $100 \times 1{,}000$, together, we have 100,000 as the product; and if we *add* 2 and 3 (which are the logarithms of $100 \times 1{,}000$) we have 5 (which is the logarithm of 100,000).

The logarithms of numbers lying between 10 and 100, 100 and 1,000, and so on (such as 96 and 154) are expressed thus:—

$$\text{Log } 96 = 1{\cdot}982271.$$
$$\text{Log } 154 = 2{\cdot}187521.$$

Here it will be seen that, as 96 lies between 10 and 100, its log must be *more* than 1 and *less* than 2, and as 154 lies between 100 and 1,000, its log must be *more* than 2 and *less* than 3; the decimal part following the 1, 2, 3, as the case may be, is, therefore, an important factor, and is to be found in tables compiled for logarithmic calculation.

We can always tell what the whole part or *index* of the logarithm is by considering how many multiples of 10 the number itself consists of; thus it will be noticed in the foregoing example, that the index is always *one less* than the number of figures in the number itself, so that for the number 100 we have 2 and for 1,000 3, and for 154 2, as the index parts of the logs of these numbers.

In the case of 154, however, we must add the decimal part to give the complete logarithm of that number.

# LATITUDE AND LONGITUDE: HOW TO FIND THEM.

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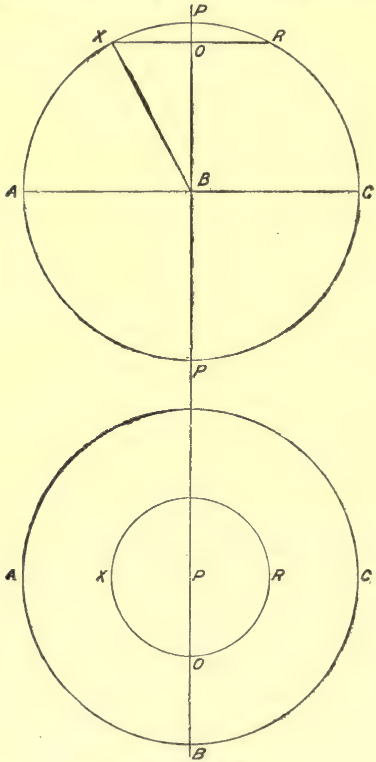
1. **Latitude.**—Latitude is the angular distance of a place on the earth's surface, *north* or *south* of the equator; or it may be defined as the altitude of the celestial pole at that place.




Figs. 1 and 2.

2. **Longitude.**—Longitude is the angular distance of a place on the earth's surface, *east* or *west* of a fixed meridian. It is

generally measured by the arc of the equator intercepted between the meridian passing through the place of observation and the fixed meridian.

Thus in Figs. 1 and 2 A B C represents the equator, which is a great circle of the earth midway between the poles P P.

Parallels of latitude are circles lying between the equator and the poles; these circles are parallel to the equator. X O R is such a circle.

3. **Meridians.**—Meridians are great circles passing through the poles, and cutting the equator at right angles. Thus, in Fig. 1, P A P C is such a meridian.

Since latitudes are measured from the equator, and longitudes from some specified meridian, then the latitude of any place, such as X, will be the arc A X, and if P B P be this fixed meridian, the longitude will be the arc O X or A B when referred to the equatorial circle.

4. **Divisions of a Circle.**—For the purposes of trigonometrical measurement, any circle is supposed to be divided into 360 equal parts called *degrees*, written thus, 360°; each degree into 60 equal parts called *minutes*, written thus, 60′; and each minute into 60 equal parts called *seconds*, written thus, 60″.

Any part of a circle may, therefore, be expressed as containing so many degrees, minutes, and seconds. Thus, the whole circle A P C P contains 360°, one-half part (as A P C) contains 180°, and one-quarter part (as A P) contains 90°. Also any intermediate part, as A X, may contain, say, 60°; or, if between 60° and 61°, it might be 60° 21′ 50″, or any other subdivision corresponding to the position of the point X.

Again, the angle A B P or A B X is measured by the number of degrees in the arcs A P or A X; hence the angle A B X will be equal to 60° or 60° 21′ 50″—or other value depending upon the position of the point X.

5. Latitudes and longitudes are measured in this way—viz., by degrees, minutes, and seconds; hence the position of the place X (Figs. 1 and 2) is known as in latitude so many degrees *north* or *south* of the equator, and as in longitude so many degrees *east* or *west* of the fixed meridian.

Thus the place represented by the point X, as drawn in the Figs., would be, say, in latitude 70° 25′ north, and in longitude 90° west.

In Britain the meridian passing through the Observatory at Greenwich is considered the fixed meridian, and is, therefore, numbered 0.

Longitudes are, therefore, known in this country as so many degrees east or west of Greenwich, and will be so considered in any after reference to them.

6. **Fixing Position by Co-ordinates.**—The fixing of the position of any place on the earth's surface is, therefore, not unlike the determining the position of a point on a plane surface by means of two lines at right angles to each other.

Thus the position of the point P may be determined by the distances at which it lies from the axes OX and OY (see Fig. 3), and if the point P be supposed to move, we may follow its movements by such measurements, taken at different parts of its course, and thus obtain a line representing its path.

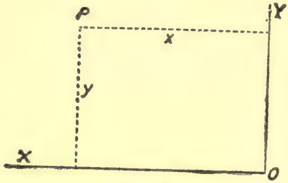



Fig. 3.

Thus in Fig. 4, if we suppose the point P to move in such a manner that the *co-ordinates* or straight lines $x$ and $y$ drawn at right angles from the axes OY and OX fix its different positions, as at $P_1$, $P_2$, $P_3$, &c., then the lines drawn through $P_1$, $P_2$, $P_3$, will show approximately its path

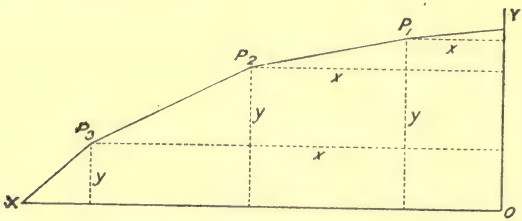



Fig. 4.

In like manner we may find the path traversed by such a moving body as a ship at sea if we know the latitudes and longitudes of different points in her path; in this case, however, the path is over a curved surface, and the positions are determined by angular measurement.

7. In land surveying we have certain definite points and lines which we can see and reckon from, whereby measurements can readily be made and positions determined.

In like manner the position of a vessel sufficiently near the coast can be determined by observations made on well-known objects ashore.

Thus, if, in Fig. 5, $S_1$ and $S_2$ be two different positions of a ship sailing on the course represented by the straight line, C O; then, if the bearing of some conspicuous object, P, on shore be determined from the position $S_1$, and again from the position $S_2$, the distance run or made good between these two positions having been noted, the observer on deck can, from these elements, obtain his distance from the object on the shore.

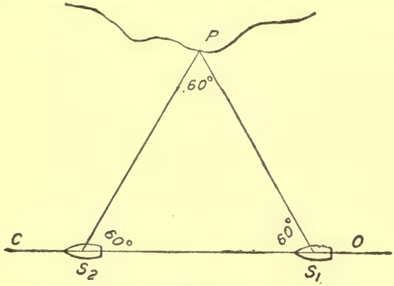



Fig. 5.

Thus, let the angle made by the lines P $S_1$ and C O be 60°, and, again, let the distance run be such that the angle made by the lines P $S_2$ and C O be also 60°, as shown in Fig. 5; then we know from mathematical principles that the triangle is an equilateral one, hence the distance to the object on shore from either of these two positions of the ship must be equal to the distance from $S_1$ to $S_2$.

In the same way we might have such a triangle as is shown by Fig. *5a*, where, if the bearing of the point P with the vessel's

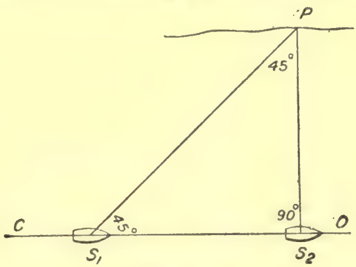



Fig. *5a*.

course, C O, from the position $S_1$ gives an angle of 45°, and, again, the second bearing from $S_2$ gives an angle of 90°, the distance, P $S_2$, is the same as that from $S_1$ to $S_2$. This is called a *four-point* bearing, from the angle 90° containing four points of the compass, or $11\frac{1}{4}° \times 4 = 45°$.

8. In the open sea, however, there are no such fixed objects, hence from very early times the sun, moon, and stars were made use of to help the mariner to determine his position.

Now, provided we know how these bodies are situated relatively to the earth, we may with more or less accuracy, depending on that knowledge and our instruments for observing, obtain some idea of our position.

Thus the pole star remains practically, to our eyes, fixed in the northern sky, and as we travel north or south it appears to rise or fall in the heavens.

In Fig. 6, let $P_1$ $P_2$ be two different positions of an observer,

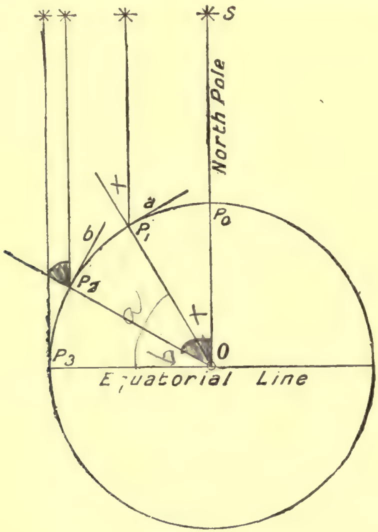



Fig. 6.

who stands in the line $P_1$ O and $P_2$ O, O being the earth's centre, then the angle at which the pole star will appear to his eye as above the horizon at $P_1$, will be that shown by the angle *a*, and when he is at $P_2$ by the angle *b*, the extreme positions being at $P_0$ and $P_3$.

At $P_3$ the star will appear on the horizon.* The several lines drawn parallel to S $P_0$ O represent the *constant direction* of the pole star as related to the earth, its distance being so great that at any two points on the earth's surface from which it may be viewed the directions are parallel.

* The horizon here referred to is that known as the *sensible* horizon, or the direction in which a level line points at the place of observation. The *visible* horizon is the line which marks where the sea and sky appear to touch (see also Article 20).

As this is an important matter when dealing with such distant bodies as the stars and sun, it may be well to point out more fully these relations.

9. **Parallax.**—If on a flat plane a pole be placed as at B (see Fig. 7), and then viewed from any point such as A, it will appear projected in the direction $B_1$; again, if viewed from the point C it will appear projected in the direction $B_2$.

This apparent shift in its position on the background $B_1$ $B_2$ is called *parallax*, and is measured by the angle A B C.

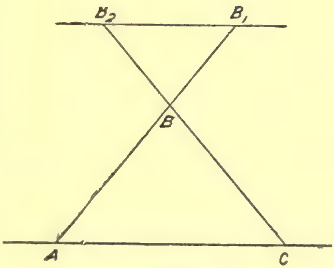



Fig. 7.

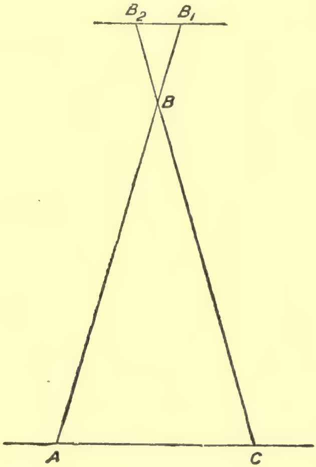



Fig. 8.

If the proportions of the triangle A B C be altered as in Fig. 8, the amount of apparent shift $B_1$ $B_2$ is less than before, hence if the object B be very remote, and the base A C of the triangle A B C very small, the angle A B C (the parallax) will become minute, and hence any object at such an inconceivable distance as the fixed stars ceases when viewed from any two points of the earth's surface to have any appreciable parallax, and consequently the lines of sight may be said to become parallel.

10. Referring again to Fig. 6, a little consideration will show that the angle $a$ is equal to the angle $P_1$ O $P_3$, and the angle $b$ to the angle $P_2$ O $P_3$, but the angle $P_1$ O $P_3$ is the latitude of the position $P_1$, and the angle $P_2$ O $P_3$ is the latitude of the position $P_2$, hence when by observation we obtain the angles $a$ and $b$, we know that we are obtaining the latitudes of these positions.

11. Such observations can only be made at night, but during

the day we have the sun, by observing whose position at certain times we can in like manner determine our latitude.

During the sun's apparent daily circuit from east to west, he rises, attains a maximum elevation, and then declines to the setting. At the maximum elevation he is in the line of a meridian passing through the point of observation, and consequently suitably placed for the observer of his altitude to determine the latitude.

The time at which the sun is in this position is known as *noon*.

Thus in Fig. 9 a person standing at $P_3$ will have the sun vertically above him; at the same time an observer at $P_2$ will

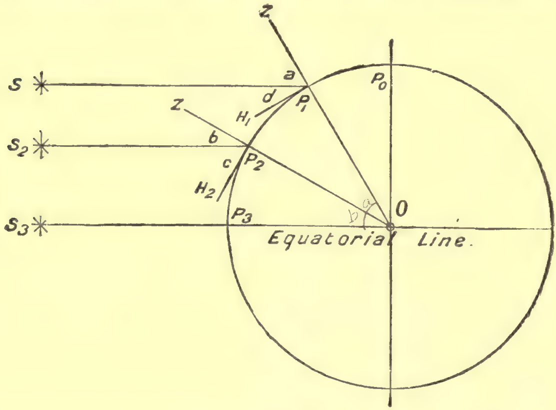



Fig. 9.

see the sun in the direction $P_2 S_2$, and an observer at $P_1$ in the direction $P_1 S_1$.

The observer at $P_3$ stands in the line $P_3$ O, and has the sun directly above him.

The observer at $P_2$ stands in the line $P_2$ O, and has the position of the sun depressed by the angle *b*, and the observer at $P_1$ sees the sun still lower down, the depression from the vertical being equal to the angle *a*, but the angle *b* * is equal to the angle $P_2 O P_3$, and the angle *a* is equal to the angle $P_1 O P_3$; therefore, as in Fig. 6, the angle *a* is the latitude of the position $P_1$, and the angle *b* is the latitude of the position $P_2$.

If, then, by means of any instrument we can measure the

* Called the *zenith distance;* the point directly overhead being known as the *zenith*. The figure of the earth is here considered to be that of a true sphere. In reality the polar diameter is a little less than the equatorial diameter.

angles *a* and *b*, we can determine the latitude of the place of observation.

Draw the line $P_2 H_2$ at right angles to the line $P_2 O$, and the line $P_1 H_1$ at right angles to the line $P_1 O$, then $H_2$ will represent the direction of the sensible horizon from $P_2$, and $H_1$ the direction of the sensible horizon from $P_1$, and, consequently, the angles *c* and *d* will be the angles of elevation or *altitude* of the sun at the places $P_2$ and $P_1$.

Since the angle $H_2 P_2 Z$ is a right angle, and in degrees is one-quarter of a circle, it is equal to 90°; hence, if we subtract the altitude from this we get the latitude, or

$$90^\circ - \text{alt.} = \text{lat.}$$

12. The above would be quite sufficient for the determination of the latitude, provided the sun were always moving in the plane of the equator; but as this is not the case, some further matters must be attended to.

13. The earth, in its annual circuit round the sun, is so placed that the axis of the daily rotation is inclined from a vertical to the plane of its orbit by an angle of 23° 28′ 40″.

Thus in Fig. 10 two positions of the earth are shown at the extremities of its orbit. P P are the poles, and E Q the equator.

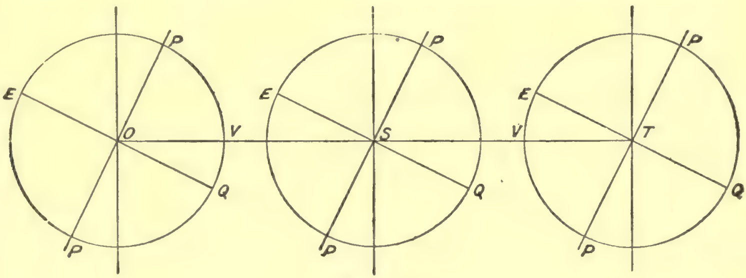



Fig. 10.

The line O S T represents the plane of the orbit, or path in which the earth moves round the sun.* S is the position of the sun.

From the above diagram it will be seen that the sun is vertical at the points V V, and these, in the positions of the earth as shown in the diagram, are removed from the equator by an angular distance equal to abont $23\frac{1}{2}°$.

* This motion is not uniform, and gives rise to corrections for time calculations (see Article 29, p. 33).

In other positions of the orbit the points V and V are nearer to the equator; at the period of the equinoxes these points are on the equator, and the conditions become the same as shown at S in Fig. 10.

14. **Declination.**—This apparent movement of the sun is called *Declination*, and must be allowed for when finding the latitude, by ascertaining its quantity from tables for the purpose.

This will be more readily understood by a consideration of Fig. 11, which shows the sun vertical at V, a position lying

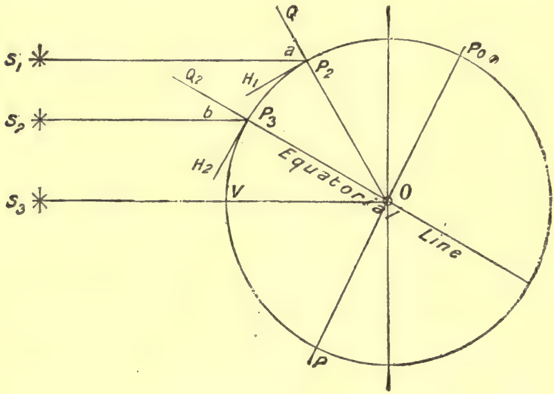



Fig. 11.

between the equator and the pole P. Hence an observer standing as before (see Fig. 9) at $P_3$, instead of having the sun vertically above him, will see it depressed by an angle equal to $b$, and an observer at $P_2$ will find that the amount of depression, as found in Fig. 9, has also increased. These additions to the former angles will be each equal to the angle $P_3$ O V, or number of degrees that the sun is beyond the equator; hence, under the conditions shown by the Fig., to get the latitude we must subtract the declination from the angle $b$ if observing from $P_3$, and from angle $a$ if observing from $P_2$.

It will be noticed that the angle $b$ is equal to the angle $P_3$ O V, and the angle $a$ to the angle $P_2$ O V, hence when we deduct the angle $P_3$ O V or declination from either of these we must get the latitude.

These conditions may be more clearly expressed by the following equations:—When the sun is over the equator, as in Fig. 9,

$$90° - \text{alt.} = \text{lat.}; \quad . \quad . \quad . \qquad (1)$$

when the sun is beyond the equator, as in Fig. 11,

$$90° - \text{alt.} - \text{declination} = \text{lat.}; \quad . \quad . \qquad (2)$$

and when the sun is between the observer and the equator,

$$90° - \text{alt.} + \text{declination} = \text{lat.} \quad . \quad . \qquad (3)$$

*Example* 1.—The observed altitude of the sun at noon on the 25th December at a place in north lat. was 10° 45′. What is the latitude? Sun's declination for that date is 23° 24′ south; then by rule (2) 90° − alt. − dec. = lat.; hence 90° − 10° 45′ − 23° 24′ = 55° 51′ N. lat.

*Example* 2.—The observed altitude of the sun at noon on the 9th May at a place in north lat. was 51° 5′. What is the latitude? Sun's declination for that date is 17° 30′ north; then by rule (3) 90° − alt. + dec. = lat.; hence 90° − 51° 5′ + 17° 30′ = 56° 25′ N. lat.

15. **Refraction.**—Refraction causes bodies when near the horizon to appear more elevated than they are in reality; this effect decreases with the elevation of the body above the horizon. At the zenith there is no refraction.

Thus the effect of refraction is so great that the sun, when seen upon the horizon, has really sunk beneath it; the effect of refraction being to apparently elevate the sun's disc through a space equal to its diameter, or about half a degree.

16. **Longitude.**—Longitude is the angular distance (as already defined, Article 2, p. 10) of any point east or west of a fixed meridian, such as that passing through Greenwich Observatory.

The sun, as he makes his apparent daily circuit in 24 hours, moves through 360°; hence, in one hour, he moves through

$$\frac{360°}{24} = 15°.$$

When the sun is on the meridian of any place it is *noon* there, hence the *time* at any place 15° *east* of that meridian will be one hour *past* noon, and of any place 15° *west* of that meridian one hour *before* noon; from this it will be seen that if we know the *difference* of the time between any place on the meridian, and any place east or west of that meridian, we have a means of determining the longitude.

Thus, if an observer at a place situated, say, 15° to the west of Greenwich, has a clock or watch showing Greenwich time, he will find that when it is *noon* with him his watch will show *one* o'clock; in other words, the watch, when the sun is on the meridian of Greenwich, showed noon, and now, in correspondence with the sun's movement through 15° of arc, it shows a movement of one hour of time measurement, or 1 p.m.

To find his longitude, therefore, the observer watches the sun until he is on the meridian of the place of observation, and at the same instant notes the time at Greenwich by his watch; the difference of time converted into degrees will be the longitude.

Thus, if the difference be one hour, the longitude will be 15° east or west, as the case may be.

The sun is always due south at noon to an observer in our northern latitudes.

17. The number of degrees corresponding to any interval of time can be found by a simple proportional statement thus:—24 hours is to the difference of time as 360° is to the longitude, or

$$24 : D :: 360 : L^\circ$$

Or,
$$\frac{360 \times D}{24} = L, \text{ or } 15\,D = L,$$

where D is the difference of time in hours, and L is the longitude in degrees.

From the above we have also

$$D = \frac{L}{15}.$$

Since 15° are passed over in 1 hour or 60 minutes, it is evident that 1° is passed over in 4 minutes, and this will be found useful for converting degrees into time.

Thus, if the difference of longitude between two places is 34°, the difference of time will be

$$\frac{34 \times 4}{60} = \frac{136}{60} = 2 \text{ h. } 16 \text{ m.}$$

Again, if we have an angle of, say, 34° 50′, then the value in time measure will be

$$\frac{34^\circ\ 50'_{4/60}}{2 \text{ h. } 19 \text{ m. } 20 \text{ sec.}}$$

18. In the foregoing description of the mode of determining the longitude, it will be seen that one of the important points is to note when the sun is on the observer's meridian.

On shore this can readily be done if we have a telescopic instrument placed exactly in the line of the meridian of the place, so that the instrument can point north and south, then the instant that the sun crosses the line of sight can be exactly noted; this will be noon at the place of observation.

At sea, however, this cannot be done, as there are no fixed points to depend upon, and, therefore, other methods and instruments must be used in the observations required.

19. **Finding the Latitude.**—On shore this can be done by means of a transit instrument as so far described, the sun's altitude being measured when the transit of the line of sight takes place.

At sea the instrument used is known as a quadrant or sextant.

Fig. 12 shows a sextant, so called because the arc A B is the

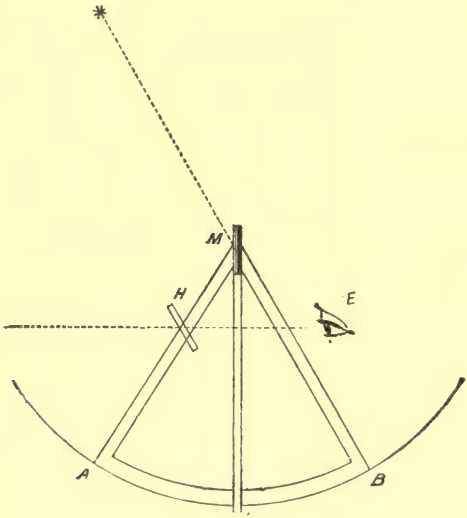



Fig. 12.

sixth part of a circle This arc is graduated into degrees, and can be subdivided into minutes and seconds.

M I is an arm moving round an axis at M, and carrying a mirror at M. H is a glass placed parallel to the side M B; one part is silvered so as to act as a mirror, the other part is clear. When a ray of light from, say a star, or the sun, falls upon the mirror at M, it is reflected to H, and again to E. The observer at E will then see the reflected image in the line E H. When that happens, the angle between the star and an object in the line E H will be equal to the angle M E H ; but as this angle is double of the angle B M I, the arc B I is graduated so as to give the exact measure of the angle M E H. In observing, the arm M I must be moved until the correspondence of reflected image and distant object takes place, the angle, as measured on the arc I B, will then give the angle between the two objects.

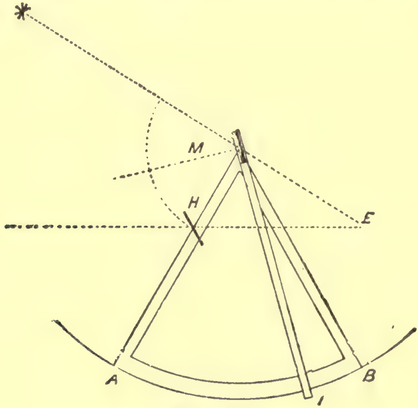



Fig. 13.

Fig. 13 shows the instrument as used when the objects are not so far apart as in Fig 12.

These instruments are carefully tested, and any permanent error found is noted and known as the *index error*, and must be allowed for when taking angular measurements.

Being provided with such an instrument, an observation for latitude can readily be made at sea, as we are no longer dependent upon an instrument only suited for fixed positions.

As noon approaches observations are made of the sun's altitude, and when his highest position is ascertained it is then noon at the place of observation. The angle of elevation of the sun above the horizon is noted, and as explained in Articles 10 to 14 the latitude is then determined.

The horizon here referred to is sometimes called the *apparent* horizon.

The apparent horizon is lower that the sensible horizon, as the eye is always situated at some height above the earth's surface.

This depression is called the *Dip.*

20. These definitions may be illustrated by Fig. 14.

Let the arc A B represent part of the sea's surface, H B a line drawn *touching* that surface at B (*i.e.*, H B is a *tangent* to the arc at B), C E a line parallel to H B.

Let this line C E be the direction of a level line, as seen by an observer standing vertically above B.

Let $H_1$ A E be a line supposed to be drawn from the eye of the observer at E to a point A, where it touches the earth's surface—*i.e.*, $H_1$ A E is a tangent to the arc A B at A.

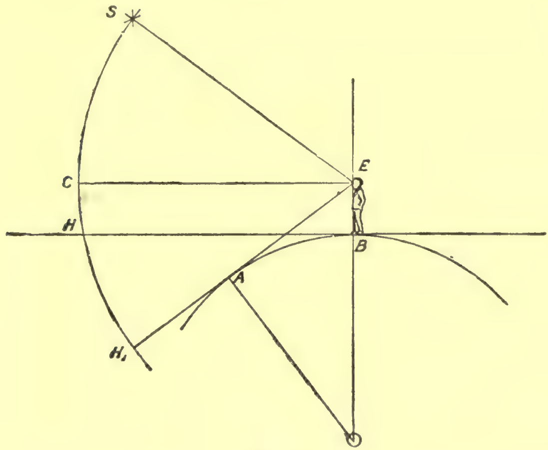



Fig. 14.

Then the angle S E C is the altitude of the object S above the level line E C, and the angle S E $H_1$ is the altitude of the object S above the line $H_1$ A E; the *difference* of these angles is the measure of the angle C E $H_1$, and this is known as the dip.

If, then, by means of a sextant, the observer brings down the image of the object S until it appears to coincide with the point A, he will find that the angle of altitude above A (or the apparent horizon) is S E $H_1$; from this he must subtract the angle C E $H_1$ or *dip* to obtain the true altitude S E C.

| | | | |
|---|---|---|---|
| *Example* 3.—Observed altitude of a star is | 32° | 15′ | 0″ |
| Height of eye, 10 feet. The depression or dip corresponding to this height is . . . . | 0 | 3′ | 3″ |
| True altitude,* . . . | 32° | 11′ | 57″ |

21. Where the observation is made on such bodies as the sun

* The true altitude is more correctly the observed altitude corrected, not only as above for *dip*, but also for *refraction* and *parallax*.

and moon, which have a visible magnitude, it is usual to measure the altitude of the upper or lower edge of the body, and subtract or add the apparent semi-diameters of the body, expressed in angular measure, so as to get the altitude of the centre of the body.

*Example* 4.—Observed altitude of the sun's lower edge, 60° 0′
Add semi-diameter or . . . . . . . . 0 16′

Altitude of centre, . . . 60° 16′

If altitude of upper edge be taken, then we have alt. = 60° 32′
Deduct semi-diameter, = . . . . . . . 16′

And we have, as before, altitude of centre, = . . . 60° 16′

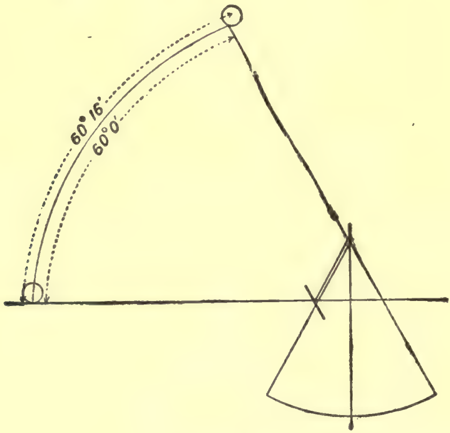



Fig. 14*a*.

Let H H H (Fig. 14*b*) represent the boundary circle of sea and sky or horizon, and let the observer, situated at the centre of this circle, wish to ascertain the altitude of the celestial pole P above his horizon line, this could be at once found if there was a visible point in the heavens, such as P, noting the celestial pole.

The nearest well-known star is *Polaris*, situated at about 1° 16′ from the celestial pole. This star, however, in common with all the other stars, has an apparent motion round the celestial pole, and in a small circle whose diameter is about 2° 32′.

It will be obvious, therefore, that an altitude of this star, such as H $S_2$ or H $S_1$, will be either too small or too large, and so for most of the other positions.

Hence, tables of the necessary corrections of the observed altitudes have been drawn up, whereby the altitude of the celestial pole may be determined, and from this the latitude.

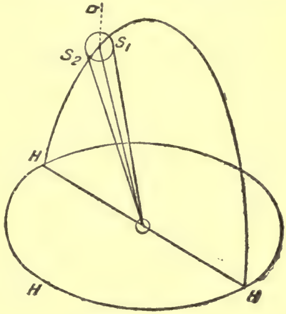



Fig. 14*b*.

As this star is only about $1\frac{1}{4}°$ from the true pole, the greatest error in latitude, as determined from an altitude of this star, cannot be more than $1\frac{1}{4}°$, due to the two extreme positions of the star when passing the meridian during the course of its small daily circuit round the true pole.

At other times the error will be less, and at the two positions at right angles to the meridian the error will be reduced to nothing.

**Artificial Horizon.**—An artificial horizon is sometimes used on shore when the natural horizon cannot be seen.

It consists mainly of a reflecting surface of some fluid, preferably mercury, in which the image of the sun can be seen, and at the same time the image of the sun, as seen in the sextant, is brought into contact. Thus, if $S_2$ be the image of the sun, as seen on the reflecting surface, then the image of the sun $S_1$, as seen in the sextant, is brought down until the two images touch; the angle read off is double of the required angle, its half will, therefore, be the altitude of $L_1$; $L_1$ is the lower limb of the image in the sextant, $L_2$ is the lower limb of the image in the artificial horizon. To get the altitude of the centre the semi-diameter has to be added.

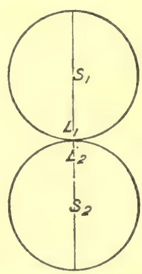



Fig. 14*c*.

22. **Finding the Longitude.**—The method of finding the latitude having been described, and shown to depend upon an observation of the altitude of the sun at noon, the finding of the longitude may be also shown to depend upon an observation of the altitude of the sun, but such observation is taken preferably at some time of the morning or afternoon, when the sun is not so high in the sky.

Thus, supposing an observation of the sun's altitude to be taken at about 8 a.m. or 4 p.m., from such an observation, by the help of a simple rule in spherical trigonometry, the angular distance of the sun from his position at noon can be calculated.

23. Before explaining this method it may be well to consider the relation of the sun's apparent daily movement round the earth, and any point on the earth's surface where the observer may be placed.

Let P, in Fig. 15, represent the north pole of the earth, and let S $S_1$ $S_2$ $S_3$ represent different positions of the sun in his apparent daily circuit from east to west.

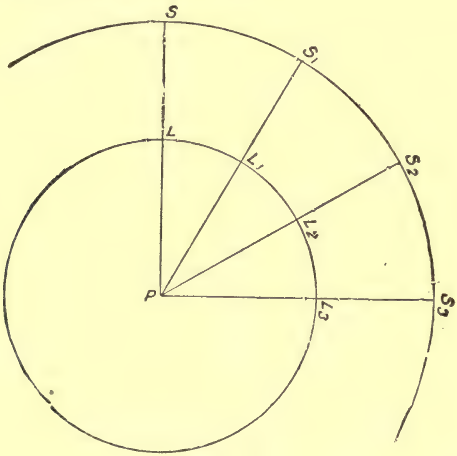



Fig. 15.

Let S be the position of the sun at noon at any place, L, and $S_1$ his position later on in the day, on a meridian passing through some other point, $L_1$, on the earth's surface, then the arc L $L_1$ will represent the angular distance travelled, and the time taken to this movement will be in the proportion of the length of the arc L $L_1$ to the whole circumference.

Thus, if L $L_1$ be 30°, then as the whole daily movement through 360° is done in 24 hours, we have—

$$360° : 30° : : 24 \text{ h.} : 2 \text{ h.}$$

Or, as formerly explained, the movement is at the rate of 15° per hour.

When the sun has got to $S_2$ the arc on the earth's surface has increased to L $L_2$, and so on, hence the angles L P $L_1$ and L P $L_2$ are known as *Hour Angles*, because, knowing the number of degrees contained in them, we can readily determine the time in hours or parts of an hour which has elapsed since the sun left the position of noon at L.

*Example* 5.—Let L P $L_1$ be any angle, say, 20° 4′ 15″. What is the corresponding local time at the place L? Now, by Article 17, we have—

$$\frac{20^\circ\ 4'\ 15_{4/60}}{1\text{ h. }20\text{ min. }17\text{ sec.}}$$

In this case 20° 4′ 15″ is the hour angle, and 1 h. 20 min. 17 sec. is the corresponding time which has elapsed during his motion from S to $S_1$, all as measured by an observer at L.

24. **Finding the Hour Angle.**—Now let us consider these relations when applied to a spherical triangle forming part of the earth's surface.

Let P (Figs. 16, 17) be one of the poles of the earth, and S and L any two points on the surface, then if D T is the equatorial

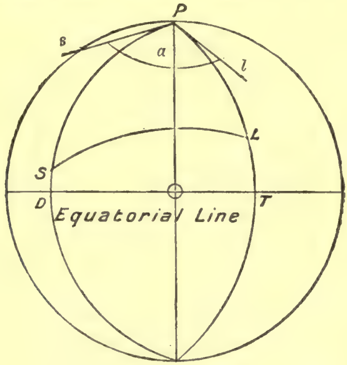



Fig. 16.

line, L T will be the latitude of the place L, and P L is the co-latitude.

Let S be a point directly below the sun at a given instant (*i.e.*, the sun is vertically overhead at S), then P S is the sun's *Polar distance*, D S his *declination*, and S L is the angular distance between the points S and L, also the angle *a* is the *hour angle*.

P S L is a spherical triangle whose sides are arcs of *great circles.**

Now, to find the values of the sides of such a spherical triangle, let an observer stationed at L take the altitude of the sun, then

* A great circle of a sphere is one which has its centre at the centre of the sphere ; the equatorial line is a great circle also ; all the meridian or longitude circles are great circles.

the altitude subtracted from 90° will be the measure of the arc S L (sometimes called the *zenith distance;* the zenith being the point of the heavens directly above the observer).

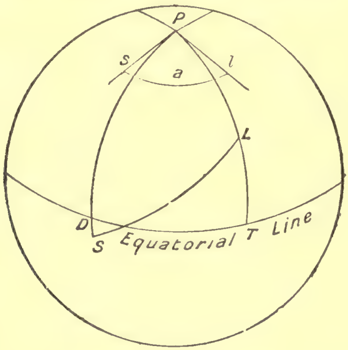



Fig. 17.

The arc P S or polar distance can always be found by referring to tables showing the declination, D S, of the sun during the year, and the arc P L is found by subtracting the latitude of the place of observation from 90°, or P L = 90° − lat.

Now, from the principles of spherical trigonometry (see Introductory Chapter, p. 7), it can be shown that—

$$\text{Cos}\ a = \frac{\text{Cos S L} - \cos \text{P L} \times \cos \text{P S}}{\text{Sin P L} \times \sin \text{P S}}$$

The angle *a* is the hour angle, and is measured by the arc contained between tangents of the arcs S P and L P, drawn from the point P where they meet.

Thus, if P *s* and P *l* be tangents to the arcs P S and P L, drawn from the common point P, then the angle *s* P *l* is the angle *a*.

From the foregoing we may write for value of cosine of hour angle—

$$\text{Cos H A} = \frac{\text{Cos co-alt} - \text{cos co-lat} \times \text{cos polar dist.}}{\text{Sin co-lat} \times \text{sin polar dist.}},$$

or more conveniently—

$$\text{Cos H A} = \frac{\text{Sin alt} - \text{sin lat} \times \text{cos polar dist.}}{\text{Cos lat} \times \text{sin polar dist.}}.$$

The change to the latter form is obtained from the rule in trigonometry that the sine of any angle is equal to the cosine of its *complement*; the complement being the difference between the angle and 90°.

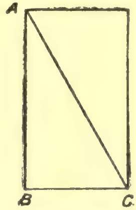



Fig. 18.

Thus, if in the above the co-alt. or S L be 73°, the co-lat. or P L be 40°, and the polar distance or P S be 70°, then the equation becomes :—

$$\text{Cos H A} = \frac{\text{Sin } 17^\circ - \sin 50^\circ \times \cos 70^\circ}{\text{Cos } 50^\circ \times \sin 70^\circ},$$

because 90 − 73 = 17, and 90 − 40 = 50.

In the right-angled triangle A B C, $\frac{\text{A B}}{\text{A C}}$ = sine of angle A C B, and $\frac{\text{B C}}{\text{A C}}$ = cosine of A C B, also $\frac{\text{A B}}{\text{A C}}$ = cosine of angle B A C, and $\frac{\text{B C}}{\text{A C}}$ = sine of angle B A C. From this we see that sine A C B = cosine B A C, and cosine A C B = sine B A C, and B A C and A C B are complementary angles, for together they are equal to a right angle or 90°.

It will be seen from the above that the sine and cosine of any angle are simply the *ratios* existing between the sides and the hypothenuse of a right-angled triangle; thus, if A C be = 1, and if A B be = ·866, and B C = ·5, then the ratios of ·866 to 1 or $\frac{\cdot 866}{1}$ is the sine of the angle A C B, and the ratio of ·5 to 1 or $\frac{\cdot 5}{1}$ is the cosine of the same angle (see also Introductory Chapter).

*Example* 6.—Let the sun's alt. be 17°, the lat. 50°, and the polar distance 70°. What is the hour angle?

$$\text{Cos H A} = \frac{\text{Sin } 17^\circ - \sin 50^\circ \times \cos 70^\circ}{\text{Cos } 50^\circ \times \sin 70^\circ}.$$

Referring to any table of natural sines and cosines, and substituting the corresponding values in above equation, we have—

$$\text{Cos H A} = \frac{\cdot 292 - \cdot 766 \times \cdot 342}{\cdot 643 \times \cdot 939} = \cdot 05035.$$

On referring again to the tables we find that ·05035 is the cosine of 87° 7′, which is, therefore, the hour angle. The time representing this angle will be found by multiplying by 4 and dividing by 60, thus—

$$\frac{87^\circ\ 7'\ {}_{4/60}}{\text{5 h. 48 min. 28 secs.}}$$

and this represents the time taken by the sun to pass through the space denoted by the angle *a*, in Figs. 16 and 17, and which has the value in the above example of 87° 7′.

25. It will be seen from the foregoing that the numerical work to be gone through in calculating the hour angle is simple, involving only subtraction, multiplication, and division.

If the values of the sines and cosines are taken to more than three places of decimals for greater accuracy in the result, then the work becomes more extended; hence, where great accuracy is wanted, it is usual to work this question by means of the logarithmic sines, cosines, &c., and the rule for finding the hour angle is expressed differently. One of the forms it assumes is this—

Let the example be as before, then

| | | | | |
|---|---|---|---|---|
| Alt. | = 17° | | | |
| Polar D. | = 70° | Cosecant | = | 10·0270142 |
| Lat. | = 50° | Secant | = | 10·1919325 |
| Sum | = 137° | | | |
| Half sum | = 68° 30′ | Cosine | = | 9·5640754 |
| Deduct Alt. | = 17° 0′ | | | |
| Difference | = 51° 30′ | Sine | = | 9·8935444 |
| | | | | 39·6765665 |
| | | Deduct | | 20 |
| | | | | 2)19·6765665 |
| Logarithmic sine of half the hour angle | | | = | 9·8382832 |

On referring to a table of logarithmic sines, &c., we find that this angle is 43° 33′ 32·5″, and doubling this we have 87° 7′ 5″ as the hour-angle, the time corresponding to which is, 5 h. 48 min. and 28 secs.

*Example* 7.—On 10th May, 1895, in a place in lat. 55° 52′, observed alt. of sun's lower limb at 3.51½ p.m. by watch was 34° 45′, and his polar distance at that time was 72° 19′ 55″, then—

| | |
|---|---|
| 34° 45′ 0″ | |
| 0° 15′ 52″ | semi-diameter. |
| 35° 0′ 52″ | |
| 0° 1′ 21″ | refraction. |
| 34° 59′ 31″ | true alt. of centre |

Then by rule we have—

| | | | |
|---|---|---|---|
| Alt. = | 34° 59′ 31″ | | |
| P.D. = | 72° 19′ 55″ | Cosec = | 10·021021 |
| Lat. = | 55° 52′ 0″ | Sec = | 10·250943 |
| | 2)163° 11′ 26″ | | |
| | 81° 35′ 43″ | Cos = | 9·159054 |
| Deduct Alt. | 34° 59′ 31″ | | |
| | 46° 36′ 12″ | Sin = | 9·861520 |
| | | | 39·292538 |
| | | Deduct | 20 |
| | | | 2)19·292538 |
| Log. sin of ½ hour angle | | . = | 9·646269 |
| Hence ½ hour angle is . | | . | 26° 17′ 1″ |
| | | | 2 |
| And hour angle . | | . . = | 52° 34′ 2″ |
| | | | 4 |
| | | | 60)210° 16′ 8″ |
| Apparent time . | | . . | 3 h. 30 min. 16 sec. |
| Equation of time, subtract, | | . | 0 3 46 |
| Mean time at place | | . . | 3 h. 26 min. 30 sec. |

26. These rules may be stated thus—

(*a*) When using the *natural* sines and cosines. From the *sine* of the altitude subtract the product of the *sine* latitude and *cosine* polar distance, and divide the result by the product of the *cosine* latitude and *sine* polar distance. The final result is the *cosine* of the hour angle.

(*b*) When using logarithmic sines, cosines, &c. Add together the altitude, polar distance, and latitude, take half the sum, and from this subtract the altitude and note the difference.

Then add together the *cosecant* of the polar distance, the *secant* of the latitude, the *cosine* of the *half sum*, and the sine of the *difference*. Subtract 20 from the sum of these and divide by 2. The result is the *logarithmic sine* of half of the hour angle.

The hour angle being found, the corresponding apparent time can be found by multiplying by 4 and dividing by 60, as already shown.*

27. **Determination of the Time.**—In all these examples the

* To facilitate these calculations, tables are published which give the *time* at once opposite the logarithmic sine of half the hour angle, thus saving the latter steps of doubling and reducing to time value

time so found is the time which has elapsed between noon and the time of observation, if the observation is made in the *afternoon.*

If made in the *forenoon*, the time representing the hour angle is the time yet to elapse from time of observation and noon.

Thus, in the example, the time corresponding to the calculated hour angle is 5 h. 48 min. 28 secs.; hence, if this is obtained from an afternoon observation, the apparent time at place of observation is 5 h. 48 min. 28 secs. p.m.

If the observation was made during the forenoon, then the apparent time at the place of observation is found by deducting hour-angle time from 24 hours, thus—

| | H. | Min. | Secs. |
|---|---|---|---|
| | 24 | 0 | 0 |
| | 5 | 48 | 28 |
| and | 18 | 11 | 32 |

is the apparent time at place of observation, reckoned from the *previous noon.*

28. Fig. 16 illustrates what we have been considering when the sun and the observer are on the same side of the equator.

Fig. 17 illustrates the conditions when the sun and observer are on different sides.

*Example* 8.—Alt. of sun on 21st Oct. = 10° 12′. Declination for that date, 10° 46′ S, therefore polar distance = 100° 46′. Latitude = 55° 52′. To find the hour angle by approximate rule—

$$\text{Cos H A} = \frac{\text{Sin } 10^\circ\ 12' - \sin 55^\circ\ 52' \times \cos 100^\circ\ 46'}{\text{Cos } 55^\circ\ 52' \times \sin 100^\circ\ 46'},$$

or $$\text{Cos H A} = \frac{\cdot 177 + \cdot 827 \times \cdot 187}{\cdot 561 \times \cdot 982} = \cdot 602,$$

which is equivalent to an hour angle of 52° 59′.*

The altitudes in these examples are supposed to be the true altitudes of the bodies—*i.e.*, the observed altitudes corrected where necessary for semi-diameter, dip, and refraction. Correction for dip and refraction is always *subtracted.*

* The sign + is used in this example instead of − as the cosine of 100 46′ is *negative*, the angle being greater than 90°; hence, the cosine of 100° 46′ is the same as cosine of 180° − 100° 46′ = 79° 14′. In other words, if we are using the cosine of an angle *greater* than 90°, we subtract the angle from 180° and use a negative sign before it. Here we have 180° − 100° 46′ = 79° 14′, and when we look up in the tables for the corresponding cosine we consider it a negative quantity and not a positive quantity as in former examples.

The same question by logarithmic method—

| | | | |
|---|---|---|---|
| Alt. | = 10° 12′ | | |
| P. D. | = 100° 46′ | Cosecant | = 10·0077134 |
| Lat. | = 55° 52′ | Secant | = 10·2509438 |
| | 2)166° 50′ | | |
| | 83° 25′ | Cosine | = 9·0593672 |
| Sub. alt. = | 10° 12′ | | |
| Difference | 73° 13′ | Sine | = 9·9810950 |
| | | | 2)19·2991194 |
| | | Sine 26° 30′ 7″ | = 9·6495597 |
| | | 2 | |
| | | 53° 0′ 14″ | |

29. We are now in a position to apply these rules to assist us in finding the longitude.

Let a ship be in lat. 57° north on 12th June, 1889, and an observation of sun's alt. taken at 7 h. 52 min. a.m., Greenwich time, equivalent to 19 h. 52 min. reckoned from previous noon.

Let the altitude be 35° 19′.

The declination for date is 23° 11′ north, hence polar distance is 90° − 23° 11′ = 66° 49′.

Then by approximate rule—

$$\text{Cos H A} = \frac{\text{Sin } 35^\circ\ 19' - \sin 57^\circ \times \cos 66^\circ\ 49'}{\text{Cos } 57^\circ \times \sin 66^\circ\ 49'},$$

or

$$\text{Cos H A} = \frac{\cdot 578 - \cdot 839 \times \cdot 394}{\cdot 545 \times \cdot 919} = \cdot 494.$$

Referring to a table of natural sines and cosines, we find that ·494 represents an angle of 60° 23′, and

$$\frac{60^\circ\ 23'_{4/60}}{4\text{ h. } 1\text{ min. } 32\text{ sec.}} = \text{hour angle.}$$

Now, subtract this from 24 h. and we have—

| H. | Min. | Sec. | |
|---|---|---|---|
| 24 | 0 | 0 | |
| 4 | 1 | 32 | |
| 19 | 58 | 28 | = apparent time at ship. |

The difference between this and the Greenwich time at time of observation is—

| | H. | Min. | Sec. |
|---|---|---|---|
| Apparent time, . . . | 19 | 58 | 28 |
| Greenwich time, . . . | 19 | 52 | 0 |
| Difference, . . . | 0 | 6 | 28 |

Now, since 4′ represents 1° or 60′, we have the following proportion :—

$$4' : 6'\ 28'' :: 1^\circ : x.$$

Reducing and working out, we have—

$$\begin{array}{l} 4' \;:\; 6'\ 28'' :: 1^\circ : \text{answer.} \\ 60 \quad\; 60 \\ \hline 240\ )388(1^\circ\ 37' \\ \quad\quad 240 \\ \quad\quad \overline{148} \\ \quad\quad\;\; 60 \\ \quad\quad \overline{8880} \\ \quad\quad 720 \\ \quad\quad \overline{1680} \\ \quad\quad 1680 \\ \quad\quad \overline{\overline{\quad\quad}} \end{array}$$

∴ 1° 37′ is the required longitude east of Greenwich, or more simply—

$$\frac{6'\ 28''}{4} = 1^\circ\ 37'.$$

Observation made on 27th February, 1895, when watch showed—

| | H. | Min. | Sec. |
|---|---|---|---|
| | 10 | 25 | 30 |
| + | 12 | 0 | 0 |
| | 22 | 25 | 30 |

| | | | | | |
|---|---|---|---|---|---|
| Declination— | | 8° | 19′ | 25″ | S. on 27th. |
| | + | 0° | 1′ | 30″ | for difference. |
| | | 8° | 20′ | 55″ | |
| | + | 90° | 0′ | 0″ | |
| | P. D. | 98° | 20′ | 55″ | |

| | | | |
|---|---|---|---|
| Obs. alt. | 20° 26′ 00″ | | |
| Semi-diam. | 0° 16′ 10″ | | |
| True alt. | 20° 42′ 10″ | | |
| Lat. | 55° 52′ 0″ | Sec. | 0·250944 |
| P. dist. | 98° 20′ 55″ | Cosec. | 0·004628 |
| Sum | 174° 55′ 05″ | | |
| Half sum | 87° 27′ 32″ | Cos. | 8·648274 |
| Remainder | 66° 45′ 22″ | Sine | 9·963217 |
| | H. Min. Sec. | | |
| H. angle | 2 6 3 | | = 18·867063 |
| | 21 53 57 | | |
| Equ. | + 0 13 0 | | |
| G. M. T. | 22 6 57 | | |
| Time by watch | 22 25 30 | | |
| | 0 18 33 | | = 4° 38′ 15″ west. |
| Long. in time | 0 17 0 | | = 4° 15′ 0″ ,, |
| Watch | 0 1 33 | fast. | |

The hour angle in the same question, worked out with natural sines and cosines, is as follows :—

| | | |
|---|---|---|
| Alt. | 20° 42′ | Sin ·353 |
| Lat. | 55° 52′ | Sin ·828, cos. ·561 |
| Polar Dist. | 98° 21′ | Cos. ·145, sin ·989, |

Hence

$$\text{Cos hour angle} = \frac{\cdot353 + \cdot828 \times \cdot145}{\cdot561 \times \cdot989} = \cdot851,$$

or an angle of 31° 41′; and, therefore, the corresponding hour angle is 2 h. 6 min.;

and 24 h. – 2 h. 6 m. = 21 h. 54 m.
Add equation of time, as before = 13 m.

Or Greenwich mean time = 22 h. 7 m.

In the remarks made and examples given (Articles 22-29), we have dealt only with *apparent time.* Thus the hour angles determined showed the angular distance (angle *a*, or arc of the equator D T, Figs. 16 and 17) between the centre of the *actual* *sun* and the meridian of the observer. And this would be quite sufficient to aid in finding the longitude were it not from the fact that the apparent motion of the sun is not uniform, and varies at different times of the year. To get an uniform measure of time, recourse is had to a *mean sun*, which is supposed to move uniformly, and the time reckoned from it is called *mean time*.

From this it will be seen that, having got *apparent time*, we must bring this to *mean time*, as our clocks and chronometers are regulated to indicate this uniform measure.

The difference between apparent and mean time is called the equation of time, and is registered with other necessary values in the *Nautical* and other almanacs. This apparent variation in the motion of the sun is due to the unequal motion of the earth in its orbit round the sun, combined with the obliquity of the axis to the ecliptic (see Fig. 10, Article 13).

To an observer, therefore, at sea, desirous of obtaining his longitude, it is necessary to know (1) the hour angle, and from that (2) the apparent time corrected by (3) the equation of time, to enable him to get (4) the *mean* time at ship.

The difference between the mean time so obtained and the Greenwich time, as noted by chronometers changed into angular measure, in the proportion of 15° to each hour, gives the longitude.

30. When the sun is over the equator (or at the equinoxes on 20th March and 22nd September) there is no declination, hence the rule for the hour angle at that time may be simply expressed as follows:—

$$\text{Cos H A} = \frac{\text{Sin alt}}{\text{Cos lat}}.$$

This follows from the polar distance at these times being equal to 90°, the cosine of which is = 0, and the sin is = 1.

*Example* 8*a*.—Alt. of sun on 20th March in lat. 56° N. was 19° 30′. What is the hour angle?

Here $$\text{Cos H A} = \frac{\text{Sin } 19^\circ\ 30'}{\text{Cos } 56^\circ} = \frac{\cdot 334}{\cdot 559} = \cdot 597,$$

or 53° 20′ of angle, which represents in apparent time 3 h. 33 min. 20 secs.

*Example* 9.—Alt. of sun on 22nd September in lat. 56° N. was 18°. What is the hour angle? Here, as before, we may write

$$\text{Cos H A} = \frac{\text{Sin alt}}{\text{Cos lat}},$$

or $$\text{Cos H A} = \frac{\text{Sin } 18^\circ}{\text{Cos } 56} = \frac{\cdot 309}{\cdot 559} = \cdot 552,$$

which represents an hour angle of 56° 29′.

The longitude may also be found by taking *similar* altitudes *before* and *after* noon. Thus, at 8.40 a.m., Greenwich time by chronometer, the true altitude of the sun's centre was 35° 31′, and by a second observation after noon it was found that when the sun's centre had the same altitude, the chronometer showed 3.56.30 p.m. If we add these two times together, and divide by 2, we get the time by chronometer when the sun was on the meridian. Thus to 8.40 a.m. and 3.56.30 p.m. add 12, and we have—

| | H. | Min. | Sec. |
|---|---|---|---|
| | 8 | 40 | 0 |
| | 15 | 56 | 30 |
| 2) | 24 | 36 | 30 |
| | 12 | 18 | 15 |

as chronometer time of sun's passage of the meridian.

| | H. | Min. | Sec. |
|---|---|---|---|
| App. time at noon, . . | 0 | 0 | 0 |
| Eq. time, . . . . . | 0 | 3 | 47 |
| Mean time at noon, . . | 23 | 56 | 13 |
| Greenwich time at noon, . | 0 | 18 | 15 |
| Diff. of time, . . . . . | 0 | 22 | 2 |

Or 5° 30′ of longitude.

31. Besides the sun we have also the moon and stars as points of observation.

The Greenwich Observatory was founded by Charles II. for the purpose of charting the heavens so as to facilitate the taking of Lunars, as they were called.

Before the chronometer was brought to be a reliable time measurer, the moon in its motion across the sky was made to play the part of a clock from which Greenwich time could be obtained. To do this it was necessary to have the moon's positions relatively to the sun carefully noted for certain periods at Greenwich, so that the angular distance of these bodies being known for any special date or during any hour of the day, an observer might be enabled to know the correct Greenwich time; the moon acting in this way like the hour hand of a clock, and showing the time by its distance from some known point (see Article 38).

32. It is obvious that we can take altitudes of the moon and stars in the same manner as we do for the sun; and if these are

taken when these bodies are on the meridian, we may find our latitude just as we do by observations of the sun, the different declinations of the moon and stars being known and recorded in tables.

33. We may also obtain longitudes from altitudes of the moon or stars, but in this case we must remember that the angular distances from the meridian so obtained do not give us the apparent time, unless we know at what hour the body passes the meridian. If this be known, we have only to add or subtract the time value of the angular distance, as in the case of the sun.

If we do not know the time at which the body passes the meridian, we have recourse to another method, which is of general application. In this case we make use of the right ascensions of the stars

34. **Right Ascension.**—Right ascension is the *time* distance of any of the heavenly bodies *measured on the equator* from the point of intersection of the equator and the ecliptic.* Thus in Fig. 10 (see p. 17), S in the central figure is such a point, as the equatorial line E Q cuts the path of the earth or ecliptic in S.

These distances are tabulated for reference, and are used for the determination of time when using altitudes of the stars.

Thus if we take an altitude of a star and work out by rule its *meridian* distance expressed in hours and fractions of an hour, we have the star's distance from the meridian in time measure.

35. Now, let us consider the case of a star to the *west* of the meridian (the meridian here spoken of is, as before, the line of longitude passing through the place of observation, hence the star when on this meridian is due south of the observer).

I. Its altitude is taken and its distance from the meridian calculated.

II. We now look up the star's *right ascension* and *add* it to the distance from the meridian.

III. The result obtained is the *right ascension of the meridian.*

IV. From this we *subtract the sun's right ascension*; and

V. The result is the *hour angle.*

This may be better understood by a consideration of Fig. 19.

Let P be one of the poles and the circle O M $S_1$ S the apparent circuit of the sun and stars.

Let P $S_1$ be the direction of the star's place $S_1$, and P S the direction of the sun's place S, and let P M be the line of the meridian through the place of observation.

* Usually called the first point of Aries, although at the present time the point of intersection has shifted.

Let P O be the direction of the point O from which right ascensions are measured, then the angular distance

O S is the right ascension of the sun,
O S $S_1$ is the right ascension of the star, and
O S $S_1$ M is the right ascension of the meridian ;

but $$O S S_1 + S_1 M = O S S_1 M.$$

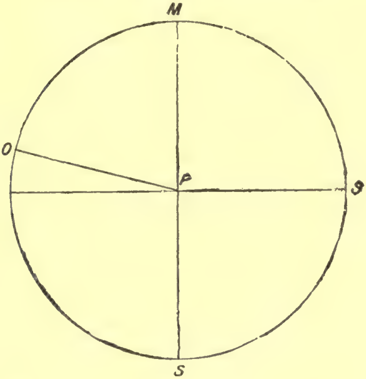



Fig. 19.

36. Hence the right ascension of the meridian is found by adding the right ascension of the star to the star's meridian distance.

And since $O S S_1 M - O S = S S_1 M$, we see that if we subtract the right ascension of the sun from the right ascension of the meridian, we have the hour angle of the sun.

37. From the foregoing it will be seen that by using the right ascensions of the sun and stars, we can find the interval of time since the sun passed the meridian, although he may not be visible—the star's position being used as a step to help us to get this time measure.

*Example* 10.—When star is *west* of the meridian.

Alt. of *Arcturus* on 8th October, 1890 = 14°.

By rule for hour angle (see Article 24) we find that the

| | H. | Min. |
|---|---|---|
| Star's distance in time from meridian or hour angle is 6 h. 16 min., . . . . . . . . | 6 | 16 |
| The star's right ascension is . . . . . . | 14 | 10 |
| Therefore, right ascension of meridian is . . . . | 20 | 26 |
| Deduct sun's right ascension, . . . . . . | 12 | 57 |
| Therefore, the sun's time is . . . . . = | 7 | 29 |

That is to say, it is 7 hours 29 minutes past noon at place of observation, or

| | H. | Min. | Sec. | |
|---|---|---|---|---|
| | 7 | 29 | 0 | p.m. apparent time. |
| Subtract | 0 | 12 | 32 | equation of time. |
| | 7 | 16 | 28 | mean time. |

*Example* 11.—When star is *east* of the meridian.

Alt. of *Aldebaran* on 7th October, 1890 = 16° 20′

By rule we find, as before, that the

| | H. | Min. |
|---|---|---|
| Star's distance in time from meridian or hour angle is 5 h. 39 min. Subtract this from 24 h., and we have . . . . . . . . | 18 | 21 |
| The star's right ascension is . . . . . . | 4 | 30 |
| Therefore, R A of the meridian is . . . . . | 22 | 51 |
| Deduct sun's right ascension, . . . . . | 12 | 54 |
| Therefore, time since sun passed meridian . . = | 9 | 57 |

| | H. | Min. | Sec. | |
|---|---|---|---|---|
| Or, | 9 | 57 | 0 | apparent time. |
| Subtract | 0 | 12 | 17 | equation of time |
| | 9 | 44 | 43 | mean time. |

The right ascension of the sun, as registered in tables for use in such problems as the foregoing, is known as the *apparent* right ascension of the sun, because, like apparent time, it is determined from the sun's actual position at the time.

When the *mean sun* is considered, we have then the right ascension of the mean sun, and this is also known as the *Sidereal Time.*

A sidereal day is measured by one complete rotation of the earth on its axis, and is the time interval between two successive transits of the same star on the meridian.

The apparent right ascension of the actual sun and the sidereal time differ from each other by the equation of time.

The daily values of sidereal time, as well as those of apparent right ascension, equation of time, &c., are registered in the *Nautical Almanac* for mean noon at Greenwich.

38. **To Find the Longitude by Lunar Distance.**—From an early period the position of the moon in her monthly circuit relatively to the stars has been kept, and now we can ascertain

from the *Nautical Almanac* the angular distance of the moon from a number of well-known stars on certain dates and at small intervals of time.

These observations made at Greenwich are all reduced to results obtainable if the observer had been situated at the earth's centre; hence when any observations are taken of a similar character and for purposes of comparison at any other part of the earth's surface, these must also be reduced to the earth's centre.

Now, if we have a table showing the Greenwich times at which the moon and a star are at certain angular distances apart, we can, by taking a measurement of the angular distance between the moon and the same star, find how such a measurement corresponds with any of the registered distances for that date, and so determine the corresponding Greenwich time.

39. Thus if, in Fig. 20, B and C represent two different positions of the moon from the star at A and O the earth's centre,

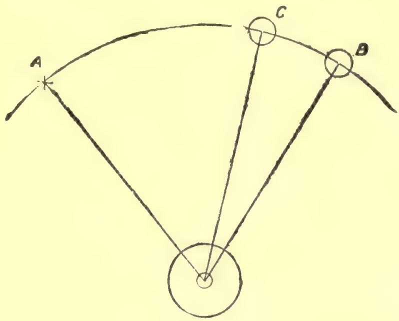



Fig. 20.

then if we know the exact time when the moon is at B we can calculate the time which will correspond to the position at C if we know the rate of motion of the moon.

40. If, therefore, by means of an observation we find the angular distance corresponding to A C, and if on referring to tables find the distance A B with the corresponding time, we can determine the time corresponding to A C or that of observation.

The moon may therefore be looked upon as the hour hand of a clock.

41. Such observations being taken upon the surface of the earth have to be corrected, as already stated, to correspond to

what would obtain if the observations could be made from the earth's centre.

Thus in Fig. 21 let O be the earth's centre and P the position of an observer on the earth's surface, then any object situated

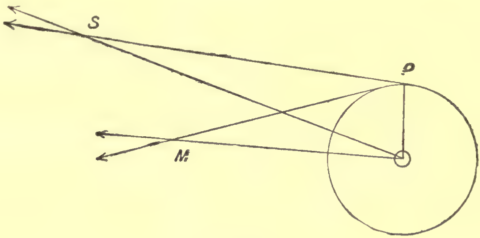



Fig. 21.

at M will appear from the position P as though projected in the line drawn through P M. If viewed from the centre O it would appear as though projected in the line O M. This apparent

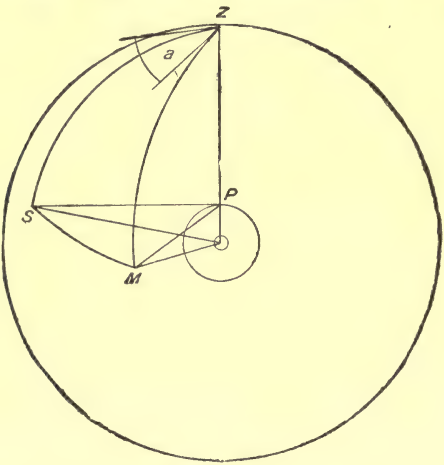



Fig. 22.

shift in position is called parallax, as already explained (see Article 9).

The further the object is away the smaller will the apparent shift of position appear.

42. Now let M denote the position of the moon, and S some other body, such as the sun or a star, the angular distance

between which we wish to determine; then by observation we can measure the angle M P S, and by calculation obtain the angle M O S, or the angle subtended by these objects at the earth's centre.

If Z (see Fig. 22) be the zenith of the observer, and M and S the observed position of the moon and sun, and M P S the observed angular distance of the centres of these bodies, then if the true altitudes of these bodies are also known, Z S M is a spherical triangle, of which the side Z M is the co-altitude of M, and Z S the co-altitude of S. And the relations of such a triangle are—

$$\text{Cos } a = \frac{\text{Cos S M} - \cos \text{Z M} \times \cos \text{Z S}}{\text{Sin Z M} \times \sin \text{Z S}},$$

but since Z M is the co-alt. of M, and Z S the co-alt. of S, we can write the equation as—

$$\text{Cos } a = \frac{\text{Cos S M} - \sin \text{alt M} \times \sin \text{alt S}}{\text{Cos alt M} \times \cos \text{alt S}}.$$

Working this out, we get the value of cos $a$ in the spherical triangle Z S M.

In this case all the angular measurements have been made from P as a point on the earth's surface. We have now to find how these are affected if supposed made from the earth's centre O.

43. Let the observed angular distance be denoted by D.
„ alt. of moon by M.
„ „ sun by S.

Then we have—

$$\text{Cos } a = \frac{\text{Cos D} - \sin \text{M} \times \sin \text{S}}{\text{Cos M} \times \cos \text{S}}.$$

Working this out, we get the value of cos $a$ in the spherical triangle Z S M.

We have now to form a new spherical triangle, the sides of which are corrected for parallax and refraction.

Let the corrected alt. of moon be denoted by $m$.
„ „ of sun „ $s$,

and the true angular distance sought for by $d$; then, since the angle $a$ is unaffected by these changes in the sides, we have—

$$\text{Cos } a = \frac{\text{Cos } d - \sin m \times \sin s}{\text{Cos } m \times \cos s},$$

or by transposition

$$\text{Cos } d = \cos a \times \cos m \times \cos s + \sin m \times \sin s,$$

and since the value of cos $a$ has already been determined, and as we know the corrected values of the other quantities on the right-hand side of the equation, we get the value of cos $d$, and by reference to a table of natural sines, the corresponding angle is found, and which is the true angular distance between the bodies, as measured from the earth's centre.

If in this equation we substitute the value of cos $a$ as given in the first equation of this Article, we have

$$\text{Cos } d = \left(\frac{\text{Cos D} - \sin \text{M} \times \sin \text{S}}{\text{Cos M} \times \cos \text{S}}\right) \times \cos m \times \cos s + \sin m \times \sin s.$$

*Example* 12.—Let observed distance of sun and moon be 39° 58′.

Observed alt. of sun . . . . = 17° 20′.
,, ,, moon . . = 25° 18′.

Let correction for moon's parallax be + 58′.
,, ,, refraction be . - 3′.

This corrected alt. of sun is 17° 20′ − 3′ = 17° 17′.
,, ,, moon is 25° 18′ + 58′ = 26° 16′.

Then cosine of corrected distance is—

$$\text{Cos } d = \left(\frac{\text{Cos } 39^\circ\, 58' - \sin 25^\circ\, 18' \times \sin 17^\circ\, 20'}{\text{Cos } 25^\circ\, 18' \times \cos 17^\circ\, 20'}\right)$$

$$\times \cos 26^\circ\, 16' \times \cos 17^\circ\, 17' + \sin 26^\circ\, 16' \times \sin 17^\circ\, 17'$$

or,

$$\text{Cos } d = \left(\frac{\cdot 766 - \cdot 427 \times \cdot 298}{\cdot 904 \times \cdot 955}\right) \times (\cdot 897 \times \cdot 955) + \cdot 443 \times \cdot 297,$$

or,

$$\text{Cos } d = \frac{\cdot 766 - \cdot 127}{\cdot 863} \times \cdot 856 + \cdot 131.$$

Hence

$$\text{Cos } d = \cdot 633 + \cdot 131 = \cdot 764,$$

and the angle corresponding to this is 40° 6′, which is the true or corrected angular distance required, represented by A C in Fig. 20.

In the *Nautical Almanac* we have the lunar angular distances with the corresponding times registered. On finding, therefore, in the table an angular value of 40° 6′, we also get the Greenwich time corresponding to that angle.

44. **Azimuth.**—The azimuth of a body is the angular distance in a horizontal plane between the object and any point north or south of the observer.

Thus in Fig. 23 the angle $b$ contained between the tangents L $x$ and L $y$ is the azimuth of the object S, P being the North Pole and L the place of the observer.

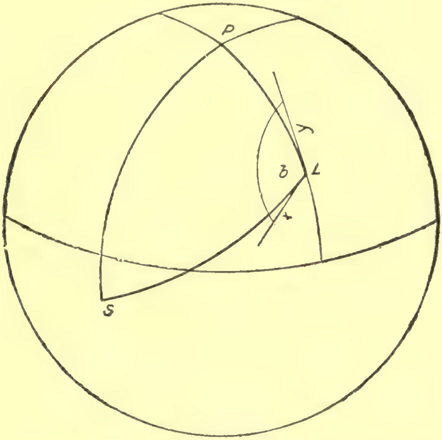



Fig. 23.

From a consideration of the rules already given when dealing with spherical triangles, we have

$$\text{Cos } b = \frac{\text{Cos P S} - \cos \text{S L} \times \cos \text{P L}}{\text{Sin S L} \times \sin \text{P L}},$$

because we are now considering the sides of the spherical triangle S P L in relation to the angle $b$ at the observer, instead of, as in former examples, considering them in relation to the angle $a$ at the pole, hence the above equation may be written—

$$\text{Cos azimuth} = \frac{\text{Sin dec} - \sin \text{alt} \times \sin \text{lat}}{\text{Cos alt} \times \cos \text{lat}}.$$

*Example* 13.—If the sun's true alt. at a place in lat. 55° 54′ N. is 19° 14′ on 20th June, what is the azimuth?

Declination for date = 23° 26′, hence polar distances is 90° − 23° 26′ = 66° 34′.

$\therefore$ Sin dec or cos P D = ·398
Sin alt = ·329
Cos alt = ·944
Sin lat = ·828
Cos lat = ·561.

Then $$\text{Cos azimuth} = \frac{\cdot 3977 - \cdot 329 \times \cdot 828}{\cdot 944 \times \cdot 561} = \cdot 2366,$$

and which represents an azimuth of 76° 19′—that is to say, the sun bears 76° 19′ from the true north.

See same question worked by logarithms as follows :—

*By Logarithms.*

| | | | | |
|---|---|---|---|---|
| Dec. | 23° | 26′ | | |
| 90 − alt. | 70° | 46′ | Cosec. | 10·024943 |
| Lat. − | 55° | 54′ | Sec. | 10·251317 |
| | 2)150° | 6′ | | |
| | 75° | 3′ | Cos. | 9·411579 |
| Subtract dec. | 23° | 26′ | | |
| | 51° | 37′ | Sin. | 9·894246 |
| | | | | 39·582085 |
| | | | | 20 |
| | | | | 2)19·582085 |

Log. sin. of half the angle, 9·791042

Therefore this angle is = 38° 10′
2

Azimuth, 76° 20′

At what time is the sun due west of the same place on 21st June?

Here, as the azimuth must be 90° and cos 90 = 0, we have by the foregoing rule—

$$0 = \frac{\cdot 398 - \sin \text{alt} \times \cdot 828}{\text{Cos alt} \times \cdot 561},$$

or $$\frac{\cdot 398}{\text{Cos alt} \times \cdot 561} = \frac{\sin \text{alt} \times \cdot 828}{\cos \text{alt} \times \cdot 561};$$

therefore $$\text{Sin alt} = \frac{\cdot 398}{\cdot 828} = \cdot 480,$$

hence $$\text{Alt} = 28° \ 42′.$$

Now, by rule of finding the hour angle we have, by using the value ·480 just found—

$$\text{Cos HA} = \frac{\cdot480 - \cdot828 \times \cdot398}{\cdot561 \times \cdot917} = \cdot2918,$$

which represents 73° 2′ of an hour angle, and equivalent to—

| | H. | Min. | Sec. | |
|---|---|---|---|---|
| | 4 | 52 | 8 | apparent time. |
| Subtract equation of time for date | 0 | 1 | 37 | |
| | 4 | 50 | 31 | |

as mean time at place when the sun will be due west.

For Greenwich time the difference of time between Greenwich and the place of observation must be added or subtracted according as the place of observation is to west or east of Greenwich.

45. **Amplitude.**—Amplitude is the angle between a heavenly body and the prime vertical, the body being on the horizon—that is to say, the angle lying on either side of the east or west points.

The rule for finding this angle follows from that given for azimuth. Since the angle $b$ (Fig. 23) may be supposed to consist

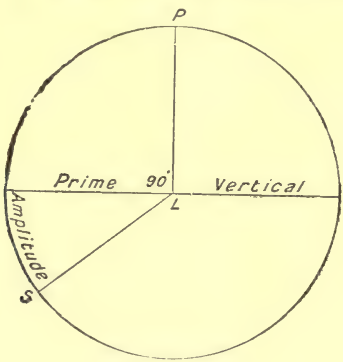



Fig. 23*a*.

of two parts, viz. :—90° + amplitude (the 90° being the angle from the pole to the prime vertical *—see Fig. 23*a*).

* *Vertical circles* are *great circles* passing through the zenith of the observer. The *prime vertical* is the great circle whose plane lies east and west. Observations for longitude are preferably taken when the sun is in or near some parts of the prime vertical.

Taking the rule for azimuth, viz. :—

$$\text{Cos azimuth} = \frac{\text{Sin dec} - \sin \text{alt} \times \sin \text{lat}}{\text{Cos alt} \times \cos \text{lat}},$$

we have first to consider that as the alt is = 0, sin alt = 0, and cos alt = 1, therefore the above equation becomes—

$$\text{Cos azimuth} = \frac{\text{Sin dec}}{\text{Cos lat}},$$

and this would enable us to find the azimuth of a body when on the horizon.

If now we consider the angle $b$, or azimuth, as made up of two parts, as 90 + amplitude (see Fig. 23$a$), we may write the above equation as—

$$\text{Cos } (90 + \text{amplitude}) = \frac{\text{Sin dec}}{\text{Cos lat}}.$$

But cos (90 + amplitude) is = sin amplitude (see Introductory Chapter), therefore we have—

$$\text{Sin amplitude} = \frac{\text{Sin dec}}{\text{Cos lat}},$$

and this is true whether the angle $b$ is equal to 90 + amplitude or 90 − amplitude.

46. **Sumner's Method of Finding the Longitude.**—Since the sun must always be vertical over some point on the earth's surface, the angular distance of an observer from that point may be found by taking the altitude of the sun and subtracting that altitude from 90°. Hence observers on any part of the earth's surface, situated at this angular distance, will see the sun at the same altitude.

In other words, if on a globe we put a mark to represent where the sun is vertical, and describe a circle with a radius whose angular measure is 90 − alt., we have what is called a *circle of equal altitude.*

If at a different time another altitude of the sun be taken from the same place, and a corresponding circle drawn, it will be found that these two circles intersect each other at two points; the observer must, therefore, be at one or other of these points.

Thus, in Fig. 24, let the large circle represent the earth, and $S_1$ $S_2$ two vertical positions of the sun, then P E Q will represent a circle of equal altitude from centre $S_1$ and P R Q another circle of equal altitude from centre $S_2$. The circles intersect at P and Q.

Let P be the point where the observer is situated, then any two small portions of these circles may be considered as straight lines (shown by the darker parts at P crossing each other in the point P). These are called *lines of position* or *lines of bearing*, and these are always at right angles to the direction of the sun.

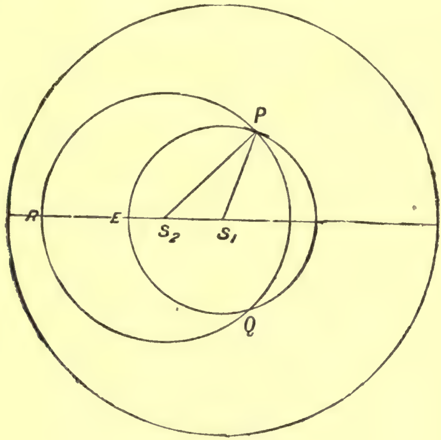



Fig. 24.

If the observer is in a ship at sea, some change of position will naturally have taken place between the times at which the altitudes were taken, the lines of position will not cross each other, and we must connect them by a line representing the course and bearing in the interval.

In practice the lines of position are found by assuming two latitudes within one degree of each other, and calculating the longitudes from an altitude and each of these assumed latitudes, and joining these positions on the chart by a short line.

This process is repeated at the second observation, using the *same* latitudes and the new altitude, hence a new pair of longitudes are found, and, therefore, a new line; these lines are lines of position, and are really approximate parts of the circles of equal altitudes obtained by this calculation.

As the ship should be somewhere on these lines at the time of observation, if the course and distance be laid off from the *first* formed line, it can be made to connect with some part of the *second* formed line by drawing from the end of it with a parallel ruler a line parallel to the first formed line of position. The *same* latitude is used because we are dealing with a circle of equal altitude.

Thus in Fig. 25 A B and C D are two lines of position found by calculation as described. A B is part of the circle of equal altitude found at a forenoon observation, and C D similarly at an afternoon observation. During the interval the course and distance may be represented by the line E F. By means of the parallel ruler, G H is laid off parallel and equal to E F; the

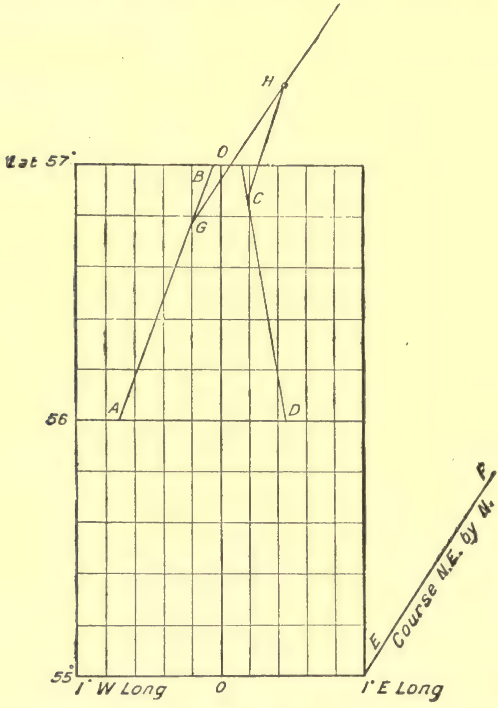



Fig. 25.

point G may be chosen on any part of the line A B; then by means of the parallel ruler draw H C parallel to A B, and the point C is the position of ship at last observation.

*Example.*—Let the assumed latitudes be 56° and 57° respectively, and the altitudes 35° 19′ and 31° 33′, then by (1) and (2) we have the line A B, and by (3) and (4) the line C D.

| | | | | | |
|---|---|---|---|---|---|
| (1) | Alt. | 35° 19′ 0″ | | | |
| | P. D. | 66° 49′ 0″ | Cosec | = | 10·0365664 |
| | Lat. | 56° 0′ 0″ | Sec | = | 10·2524383 |
| | Sum | 158° 8′ 0″ | | | |
| | Half sum | 79° 4′ 0″ | Cos | = | 9·2779911 |
| | Ded. alt. | 35° 19′ 0″ | | | |
| | | 43° 45′ 0″ | Sin | = | 9·8398004 |
| | | | | | 39·4067962 |
| | | | | | 20 |
| | | | | | 2)19·4067962 |
| | Log. sin of ½ hour angle | | | = | 9·7033981 |

Or, angle = 30° 20′ 22″
2

hence hour angle = 60° 40′ 44″

| | | H. | Min. | Sec. |
|---|---|---|---|---|
| Or, | | 4 | 2 | 42 |
| | | 12 | 0 | 0 |
| | | 7 | 57 | 18 |
| | Eq. T. Sub. | | | 24 |
| | | 7 | 56 | 54 |
| | G. M. T. | 7 | 59 | 48 |
| | | 0 | 2 | 54 |

Or 43′ 30″ W. long.

| | | | | | |
|---|---|---|---|---|---|
| (3) | Alt. | 31° 33′ 0″ | | | |
| | P. D. | 66° 47′ 46″ | Cosec | = | 10·0366317 |
| | Lat. | 56° 0′ 0″ | Sec | = | 10·2524383 |
| | | 2)154° 20′ 46″ | | | |
| | | 77° 10′ 23″ | Cos | = | 9·3463670 |
| | | 31° 33′ 0″ | | | |
| | | 45° 37′ 23″ | Sin | = | 9·8541493 |
| | | | | | 39·4895863 |
| | | | | | 20 |
| | | | | | 2)19·4895863 |
| | Log. sin of ½ hour angle | | | = | 9·7447931 |

Or, angle = 33° 45′ 10″

| | | |
|---|---|---|
| | | 2 |

hence hour angle = 67° 30′ 20″

Or,

| | H. | Min. | Sec. |
|---|---|---|---|
| | 4 | 30 | 1 |
| Eq. T. Sub. | | | 20 |
| | 4 | 29 | 41 |
| G. M. T. | 4 | 28 | 0 |
| | 0 | 1 | 41 |

Or 25′ 15″ E. long.

| (2) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Alt. | 35° | 19′ | 0″ | Sin | ·5781 | | |
| P. D. | 66° | 49′ | 0″ | Sin | ·919 | Cos | ·394 |
| Lat. | 57° | 0′ | 0″ | Sin | ·838 | Cos | ·544 |

$$\text{Cos HA} = \frac{\cdot5781 - \cdot838 \times \cdot394}{\cdot544 \times 919} = \frac{\cdot5781 - \cdot3302}{\cdot500} = \cdot4958$$

and hour angle = 60° 16′ 38″

Or,

| | H. | Min. | Sec. |
|---|---|---|---|
| | 4 | 1 | 6 |
| | 12 | 0 | 0 |
| | 7 | 58 | 54 |
| Eq. T. Sub. | | | 24 |
| | 7 | 58 | 30 |
| G. M. T. | 7 | 59 | 48 |
| | 0 | 1 | 18 |

Or 19′ 30″ W. long.

| (4) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Alt. | 31° | 33′ | 0″ | Sin | ·5232 | | |
| P. D. | 66° | 47′ | 46″ | Sin | ·919 | Cos | ·394 |
| Lat. | 57° | 0′ | 0″ | Sin | ·838 | Cos | ·544 |

$$\text{Cos HA} = \frac{\cdot5232 - \cdot838 \times \cdot394}{\cdot544 \times \cdot919} = \frac{\cdot5232 - \cdot3302}{\cdot500} = \cdot386$$

and hour angle = 67° 17′ 0″

Or,

| | H. | Min. | Sec. |
|---|---|---|---|
| | 4 | 29 | 8 |
| Eq. T. Sub. | | | 20 |
| | 4 | 28 | 48 |
| G. M. T. | 4 | 28 | 0 |
| | 0 | 0 | 48 |

Or 12′ E. long.

*Note.*—The working in (2) and (4) is shown by using *natural* sines and cosines instead of logarithmic equivalents.

47. **Longitude from Observation at Sunset.**—If from a ship in lat. 44° 50′ N. the sun be observed to set at 9 h. 46 min. 58 sec., as noted by chronometer, find the longitude. Date, 13th September, 1895.

Let the altitude be that of the sun's lower limb = 0° 0′, and let the corrections for semi-dia. be 16′, to be *added;* refraction 33′, and dip 5′, to be *subtracted.* We have as the final correction to be made for true altitude 22′.

Let Polar dist. be 86° 20′ N., then by the rule given on page 31 we have :—

| | | | | |
|---|---|---|---|---|
| Alt. = | 0° | 0′ | | |
| P. D. = | 86 | 20 | Cosec | 0·000889 |
| Lat. = | 44 | 50 | Sec | 0·149255 |
| | 131 | 10 | | |
| Subtract | | 22 | | |
| | 2)130 | 48 | | |
| | 65 | 24 | Cos | 9·619386 |
| Add | | 22 | | |
| | 65 | 46 | Sin | 9·959938 |
| | | | | 2)19·729468 |
| | | | | 9·864734 = Sin 47° 5 |
| | | | | 2 |
| | | | | Hour angle 94° 10′ |

| | H. | Min. | Sec. |
|---|---|---|---|
| Or, expressed in time measurement, | 6 | 16 | 40 |
| Equation of time, . . . . | 0 | 4 | 14 |
| Mean time at ship at sunset, . . | 6 | 12 | 26 |
| Mean time at Greenwich, . . | 9 | 46 | 58 |
| Difference of time, . . . . | 3 | 34 | 32 |

Or 53° 38′ W. long.

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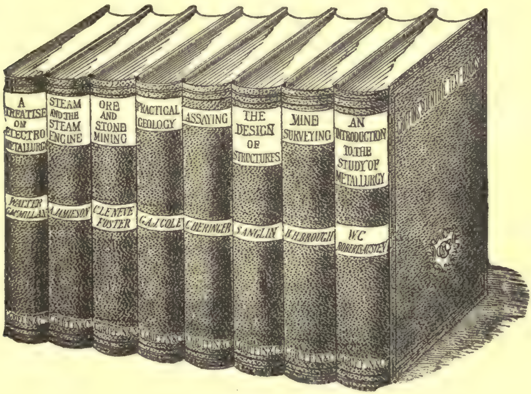


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